Planning and operation of an energy Hub Model for Reducing Grid Electricity Dependency in a virtual Industrial Park

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ABSTRACT

Large industrial parks are major energy consumers whose heavy reliance on the national grid often leads to production losses and equipment damage during power outages, significantly impacting their financial performance. To address this critical issue, this study develops a linear Energy Hub (EH) model for the optimal planning and operation of an integrated energy system. The proposed linear framework ensures computational efficiency while effectively managing the multi-energy demands of the park and reducing its grid dependency. Simulation results demonstrate that this configuration increases electricity supply reliability by 1.01% and reduces maximum grid dependency by at least 20%. In addition, the model's economic robustness was tested through a sensitivity analysis on grid electricity costs, showing that a 15% price increase makes the internal generation assets of the hub more economically favorable, effectively minimizing grid usage. This enhanced autonomy directly mitigates the impact of grid blackouts, safeguarding industrial processes and protecting revenue streams.

Keywords: *Energy Hub, Industrial Parks, Grid Dependency*

1. *INTRODUCTION*

Energy efficiency and carbon emissions have attracted increasing attention in recent years [1]. Global warming has become one of the major problems of human society; promoting the reduction of CO_2 emissions and developing a low-carbon society is of great importance for sustainable development [2]. As the primary greenhouse gas, CO_2 accounts for more than 70% of total greenhouse-gas emissions, which makes CO_2 mitigation a central objective in modern energy-system studies [3]. At the same time, the growing penetration of variable renewables, particularly wind and photovoltaic (PV) generation, is reshaping the supply mix and offering scalable pathways to decarbonize end-uses [5]. On the demand side, rising cooling needs are changing electricity consumption patterns in buildings and districts: cooling already accounts for around one-fifth of global building electricity and is the fastest-growing end-use, exacerbating summer peaks and straining local grids under current policies [7], [9]. These trends make electricity-based cooling management and on-site PV utilization key levers for sustainable operation.

Within this context, the energy hub (EH) has emerged as a standard abstraction to model multi-carrier conversion, storage, and flows (e.g., electricity–heat–cooling) and to co-optimize investment and operation as technology portfolios evolve [8], [10], [11]. In this work, we adopt an EH that prioritizes electric (vapor-compression) chillers for cooling and on-site PV for local electricity supply, explicitly aligning the model with cooling-dominant districts and avoiding technologies outside our scope. For EHs with notable solar potential, prior studies show that capturing interactions among generation, the network, and demand is essential: PV output is temporally aligned with typical cooling peaks, and coordinated operation can reduce imports and improve local utilization of renewables [12]. To address renewable variability and operational constraints, energy storage systems and demand management have been widely explored as means to balance supply–demand, raise self-consumption, and shave peaks in integrated energy settings [13], [14]. Moreover, planning and dispatch formulations that account for uncertainty in renewables and load (e.g., stochastic/bi-level models) further improve operational robustness and cost performance in community-scale integrated energy systems [15], [16].

Building on these insights, this paper develops a techno-economic framework for a solar-enabled, electricity-centric EH that (i) advances electrification of the hub by deploying electric chillers and on-site PV, and (ii) reduces reliance on the grid by maximizing local PV utilization and mitigating import peaks through coordinated operational policies (and storage where applicable). The formulation and case studies are designed to quantify the trade-offs among total cost, emissions, and grid dependence, providing actionable design guidance for cooling-dominant EHs under realistic network limits. Finally, we note that within the reviewed literature, heat-pump-oriented studies (e.g., [6]) primarily target emissions and energy savings, and do not demonstrate a reduction of dependence on the electricity grid as a primary outcome. However, in the above studies [15–20], the energy efficiency was all considered as constant and the influence of off-design conditions was ignored. In fact, the energy efficiency changes with different working conditions. Some methods have been adopted to consider uncertainty in energy efficiency.

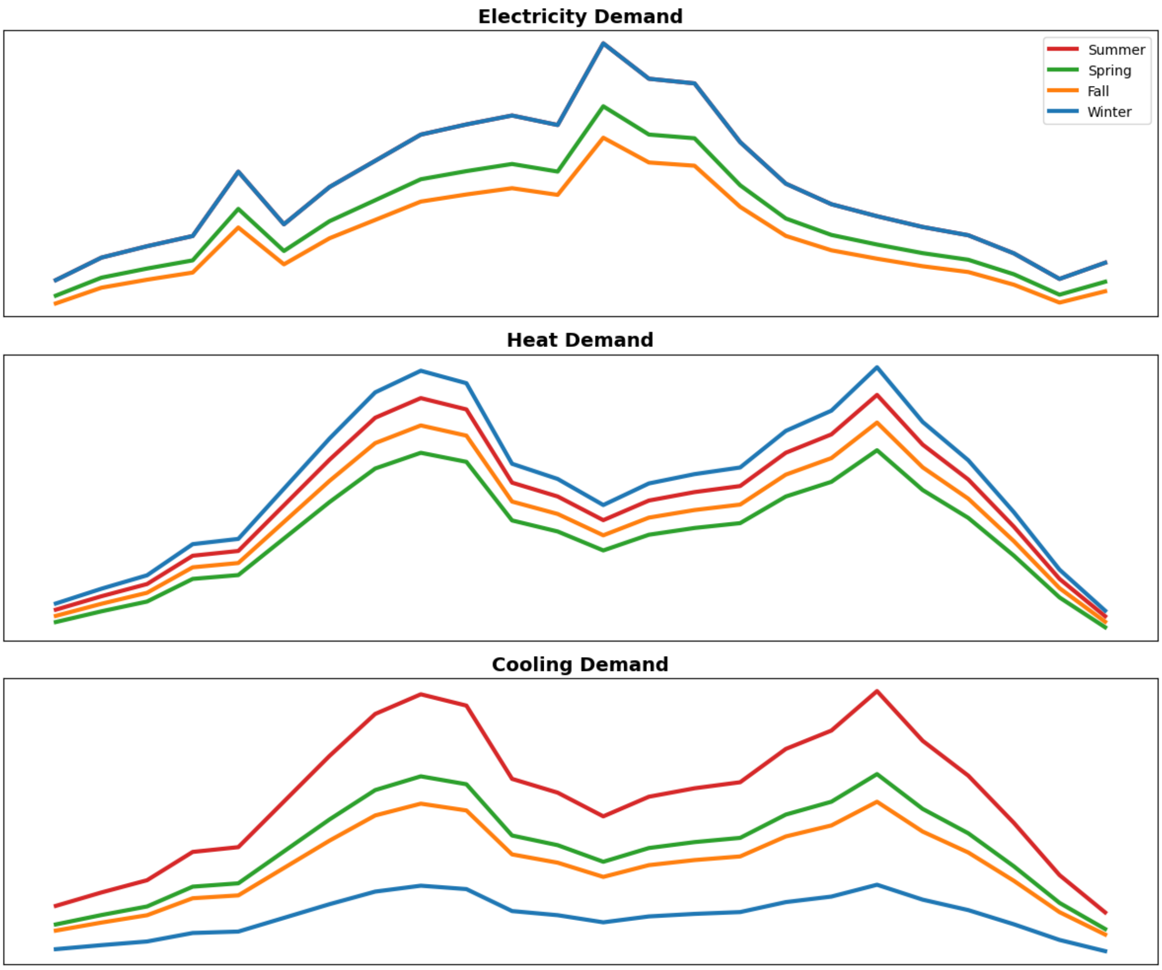

Fig. 1. Electricity, Heating and Cooling demands of each season in 24 hours

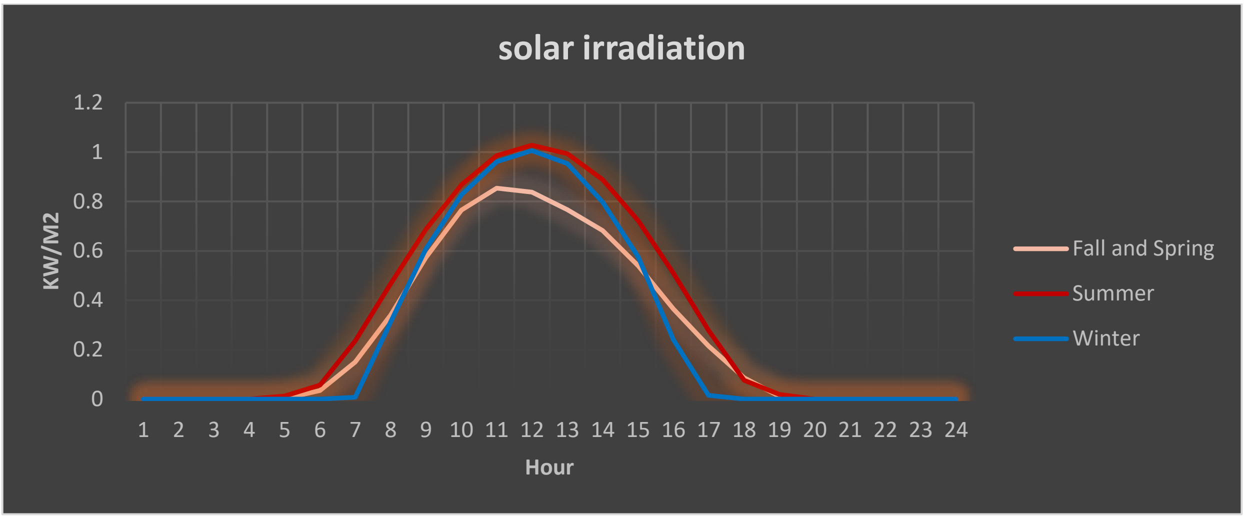

Fig. 2. Solar Irradiation for 4 seasons during the day

2. Mathematical Modelling

1. Capex and Opex Costs

Equipment	*battery*	*AC*	*CC*	*CHP*	*Boiler*	*Tranfo*	*Wind*	*PV*	*HP*
CAPEX	*100*	*220*	*170*	*750*	*580*	*500*	*1000*	*450*	*800*
OPEX (%)	*3.0*	*1.0*	*8.0*	*3.0*	*3.5*	*3.0*	*5.0*	*3.0*	*15.0*

Table 2- Constants, Variables, Sets and indices

Category	Symbol	Value / Type	Unit	Description
Indices	Y	0 to 9	–	Year (0 = 2025, 9 = 2034)
	S	{Summer, Spring, Fall, Winter}	–	Season
	t	1 to 24	h	Representative hour
	k	{battery, ac, cc, chp, boiler, trafo, wind, pv, hp}	–	Equipment index
Financial	r	0.10	–	Annual discount rate
	G	14	Toman/kWh	Grid electricity price
	H	8760	h/year	Total hours in a year
	N	96	–	Number of representative time blocks (4×24)
Emission Factor (gas)	CO2gas	1.88	kg/MWh	CO_2 emission factor of natural gas (input energy)

Category	Symbol	Value / Type	Unit	Description
Emission Factor (grid)	CO2grid	0.50	kg/MWh	CO_2 emission factor of grid electricity
Transformer	ηtrafo	0.97	–	Transformer efficiency
Big M	M	1000	MW	Big-M constant (prevents simultaneous charge/discharge)
Binary Variable	$u_{y.s.t}$	{0,1}	–	Binary: 1 = charging, 0 = discharging
CHP	ηel,chp	0.35	–	CHP electrical efficiency
	ηth,chp	0.30	–	CHP thermal efficiency
Absorption Chiller	ηac	0.70	–	Absorption chiller efficiency
Compression Chiller	COPcc	4.0	–	Compression chiller coefficient of performance
Heat Pump	COPhp	3.5	–	Heat pump coefficient of performance
Boiler	ηboiler	0.70	–	Boiler efficiency
PV System	ηpv	0.18	–	PV panel efficiency
PV system	Aunit,pv	1000	m²/MW	Land required per MW of installed PV
PV system	Amax,pv	10,000	m²	Maximum available land for PV
PV system	IRRs,t	data	kW/m²	Solar irradiance at season sss, hour ttt
Wind System	CFs,twind	(0.7 in summer, 0.6 in other seasons)	–	Wind capacity factor at season sss, hour ttt
Demand Profiles	$P_{s.t}^{dem}$	data	MW	Electricity demand
Demand profile	$H_{s.t}^{dem}$	data	MW	Heat demand
Demand profile	$C_{s.t}^{dem}$	data	MW	Cooling demand
Penalty	Slack	10910^9109	Toman/MW	Penalty coefficient for slack variables
CHP	G_{CHP}		m^3	Gas usage of CHP
CHP	LHV_{gas}	10	$\frac{Kwh}{m^3}$	Gas LHV
CHP	$P_{y,s,t}^{CHP}$		Mw	CHP power production
CHP	$H_{y,s,t}^{CHP}$		Mw	CHP heat production
CHP	$P_{y,s,t}^{CHP,max}$		Mw	CHP max capacity in energy production
Boiler	G_{boiler}		m^3	Gas usage of boiler
Boiler	$H_{y,s,t}^{boiler}$		Mw	Boiler heat production
Boiler	$H_{y,s,t}^{boiler,max}$	60	Mw	Max boiler heat production
Heat Pump (HP)	$H_{y,s,t}^{HP}$		Mw	HP heat production

Category	Symbol	Value / Type	Unit	Description
Heat Pump (HP)	$P_{y,s,t}^{HP}$		Mw	Power input of the HP
Compression Chiller (CC)	$C_{y,s,t}^{CC}$		Mw	CC cooling production
Compression Chiller (CC)	$P_{y,s,t}^{CC}$		Mw	Power input of the CC
Absorption Chiller (AC)	$C_{y,s,t}^{AC}$		Mw	AC cooling production
Absorption Chiller (AC)	$H_{y,s,t}^{AC}$		Mw	Heat input of the AC
Battery	$P_{y,s,t}^{ch}$		Mw	Charging power of the battery
Battery	$P_{y,s,t}^{dch}$		Mw	Discharging power of the battery
Battery	$P_{y,s,t}^{ch,max}$		Mw	Max Charging power of the battery
Battery	$P_{y,s,t}^{dch,max}$		Mw	Max Discharging power of the battery
Battery	$SOC_{y,s,t}^{bat,max}$	600	Mw	Max State of charge
Battery	$SOC_{y,s,t}^{bat,min}$	10	Mw	Min State of charge

Objective Function (OF)

First of all, the OF has to be defined. The OF, in this study, is to minimize the total costs of operation and investment of the components, for each season, for each time. Thus, the OF is illustrated as below:

$$OF = min\left(C_k^{INV} + C_{k,y,s,t}^{OP}\right) \qquad \forall k \in \{PV, wind, CHP, AC, CC, HP, BAT, GRID, Boiler\}, y \in Y, s \in S, t \in T$$

The operational cost is calculated using the interest rate, r. For converting the future operational costs, they have to be divided by (1+r) ^y which n demonstrates the years of the modelling.

$$Present\ Value = \frac{Future\ Value}{(1+r)^y} \qquad \forall y \in Y$$

In OF, the k represents the types of technologies.

Constraints

First, the constraints of the components have to be illustrated. These constraints are divided into 5 parts: 1. Heating constraints, 2. Cooling constraints, 3. Electricity constraints, 4. Energy balances and 5. Emission constraints.

Heating constraints

CHP

The first component is CHP, which is able to produce both heat and electricity. Thus, its performance is divided into two part: 1. Heat production and 2. Electricity production.

$$P_{y,s,t}^{CHP} = \eta_{el,CHP} * G_{CHP} * LHV_{gas} \quad \forall\, y \in Y, s \in S, t \in T \qquad (2\text{-}2)$$

$$H_{y,s,t}^{CHP} = \eta_{h,CHP} * G_{CHP} * LHV_{gas} \quad \forall\, y \in Y, s \in S, t \in T \qquad (2\text{-}3)$$

$$P_{y,s,t}^{CHP} + H_{y,s,t}^{CHP} \leq P_{y,s,t}^{CHP,max} \quad \forall\, y \in Y, s \in S, t \in T \qquad (2\text{-}4)$$

The constraints (2-2) and (2-3) illustrate the power and heat production of the CHP by multiplying the efficiency of each energy production and the natural gas input for each. The unit of natural gas is based of cubic meter. Thus, it should be multiplied by the LHV of the natural gas to calculate the energy output of each cubic meter of the natural gas. In constraint (2-4), it is shown that the total energy yield of the CHP has to be equal or fewer than a maximum limitation. This upper limitation is a decision variable.

Boiler

The mathematic model of the boiler is very similar to the heat production of the CHP. However, the efficiency of Boiler is 70 percent and thus, the constraint of the boiler is as below:

$$H_{y,s,t}^{boiler} = \eta_{h,boiler} * G_{boiler} * LHV_{gas} \quad \forall\, y \in Y, s \in S, t \in T \qquad (2\text{-}5)$$

Owing to concentrating of less pollutant components, there is a hard limit of the maximum capacity of the boiler. This constraint says the heat production of the boiler should not exceed 60 megawatts.

$$H_{y,s,t}^{boiler,max} \leq 60Mw \quad \forall\, y \in Y, s \in S, t \in T \qquad (2\text{-}6)$$

Heat Pump (HP)

HP is an electricity user component that can produce both heating and cooling. Nevertheless, in this study, we only considered HP as a heat producer. The constraint of the HP shows the multiplication of its COP and the electricity it utilizes:

$$H_{y,s,t}^{HP} = COP_{HP} * P_{y,s,t}^{HP} \quad \forall\, y \in Y, s \in S, t \in T \qquad (2\text{-}7)$$

Cooling constraints

The cooling production components are (Absorption Chiller) AC and (Compression Chiller) CC. The AC utilizes heat and make cooling, but the CC uses electricity for doing that.

$$C_{y,s,t}^{CC} = COP_{CC} * P_{y,s,t}^{CC} \quad \forall\, y \in Y, s \in S, t \in T \qquad (2\text{-}8)$$

In the eq, (2-8), the COP of the CC has to be multiplied by the input electricity from the electricity production technologies. The COP of CC is considered to be 4 as shown in table 2.

$$C_{y,s,t}^{AC} = \eta_{AC} * H_{y,s,t}^{AC} \quad \forall\, y \in Y, s \in S, t \in T \qquad (2\text{-}9)$$

As it was mentioned before, the AC uses heating to make cooling.

Electricity components

Battery

First, it should be satisfied that the battery power is equal or less than the maximum quantity. This maximum limitation is designed for both the charging and discharging processes. These constraints are designed as below:

$$P^{ch}_{y,s,t} \leq P^{ch,max}_{y,s,t} \qquad \forall\, y \in Y, s \in S, t \in T \qquad \text{(2-10)}$$
$$P^{dch}_{y,s,t} \leq P^{dch,max}_{y,s,t} \qquad \forall\, y \in Y, s \in S, t \in T \qquad \text{(2-11)}$$

The next constraint of the battery is its State of the Charge (SOC). The SOC of the battery at time t is equal to the SOC at time t-1 plus the amount of charging at time t minus the amount of discharging.

$$SOC^{bat}_{y,s,t} = SOC^{bat}_{y,s,t-1} + (\eta_{AC} * P_{ch,y,s,t}) - (\frac{P_{dch},y,s,t}{\eta_{dch}}) \qquad \forall\, y \in Y, s \in S, t \in T \qquad \text{(2-12)}$$

Also, the SOC of the first time of a season is equal to the SOC of the time 24th of the previous season plus the charging of the first time in the current season minus the amount of discharging in that season.

$$SOC^{bat}_{y,s,1} = SOC^{bat}_{y,s-1,24} + (\eta_{AC} * P_{ch,y,s,1}) - (\frac{P_{dch},y,s,1}{\eta_{dch}}) \qquad \forall\, y \in Y, s \in S, t \in T \qquad \text{(2-13)}$$

In addition to the above-mentioned constraints, the SOC of the battery should be limited to an upper and a lower amount of charge.

$$SOC^{min}_{y,s,t} \leq SOC^{bat}_{y,s,t} \leq SOC^{max}_{y,s,t} \qquad \forall\, y \in Y, s \in S, t \in T \qquad \text{(2-14)}$$

Here, it is worth-noting that the processes of charging and discharging cannot be happed simultaneously. For this prevention, we defined a binary variable for charging, $u_{y,s,t}$, that does have two values: {0, 1}. If it is 0, then the discharging is happening but if it is 1, it means the battery is being charged.

$$u_{y,s,t} \in \{0,1\} \qquad \forall\, y \in Y, s \in S, t \in T \qquad \text{(2-15)}$$

However, when applying binary variables to the model and multiply it to the amount of charging or discharging, a non-linear constraint is designed and this means our model, which is a LP, is not able to solve it. For tackling this problem, we utilized the rule of big M. the binaries should be multiplied by a big M (which is a very hard penalty) and says if the battery is, for instance, being charged, happening the discharge would cost a lot and as the model has targeted the minimization of the cost, this would not be acceptable and moreover, the model prevent doing that.

$$P^{ch}_{y,s,t} \leq M * u_{y,s,t} \qquad \forall\, y \in Y, s \in S, t \in T \qquad \text{(2-16)}$$

$$P^{d\,ch}_{y,s,t} \leq M * (1 - u_{y,s,t}) \qquad \forall\, y \in Y, s \in S, t \in T \qquad \text{(2-17)}$$

Solar PV

$P^{PV}_{y,s,t} \; = \; A_{PV} * IRR_{s,t} * \eta_{PV} \quad \forall\, y \in Y, s \in S, t \in T$ *(2-18)*

The constraint (2-15) depict the power production of the PV. In this equation, the area should be multiplied by the irradiation in 24 hours in each season and then, the result has to be multiplied by the efficiency of the PV system. The maximum area that is free for PV system is 15 hectares.

Wind Turbines

There is no limitation for wind power in this study as the wind energy can be produced constantly. Also, the capacity of the wind would be calculated by the model itself.

$P^{wind}_{y,s,t} \; = \; CF_{s,wind} * P_{max,wind} \quad \forall\, y \in Y, s \in S, t \in T$ *(2-19)*

CHP

The electricity constraint of the CHP is depicted in eq, (2-2).

Grid

The electricity input from the grid has to be supplied through the transformators and the electrical components. The total efficiency of these components is considered to be 0.98. Also, it has to be noted that there is not limit on grid electricity usage as we want our system to naturally omit the grid electricity usage and not by applying some hard limitations.

$P^{P-transfo}_{y,s,t} \; = \; P^{P-grid}_{y,s,t} \; * \; \eta_{transfo} \quad \forall\, y \in Y, s \in S, t \in T$ *(2-20)*

Electricity Balance

$$P^{P-grid}_{y,s,t} + P^{wind}_{y,s,t} + P^{PV}_{y,s,t} + P^{CHP}_{y,s,t} + P^{dch}_{y,s,t} + P^{slack}_{y,s,t} = P^{dem,el}_{y,s,t} + P^{ch}_{y,s,t} + P^{CC}_{y,s,t} + P^{HP}_{y,s,t}$$

$$\forall\, y \in Y, s \in S, t \in T \quad \text{(2-21)}$$

The electricity balance says the electricity produced by the electricity production technologies should be equal to the sum of electricity of demand, and the electricity user technologies. Here, the electricity produced by PV Wind, CHP, Grid, Discharge of Battery plus a slack that shows the unmet electricity (if it is unmet) should be equal to the demand of electricity plus the electricity needed for CC, HP, charging of the Battery and the electricity demand.

The same balance is written for heating and cooling balance:

$H^{boiler}_{y,s,t} + H^{CHP}_{y,s,t} + H^{HP}_{y,s,t} + H^{slack}_{y,s,t} = H^{dem}_{y,s,t} + H^{AC}_{y,s,t} \quad \forall\, y \in Y, s \in S, t \in T$ *(2-22)*

For heat balance, the heat produced by HP, CHP and Boiler should be equal to heating demand plus AC.

Similar to the last two energy balances, the cooling balance is ab below:

$$C^{AC}_{y,s,t} + C^{CC}_{y,s,t} + C^{slack}_{y,s,t} = C^{dem,}_{y,s,t} \quad \forall\, y \in Y, s \in S, t \in T \qquad (2\text{-}23)$$

Emission Constraints

Finally, the emission constraints have to be applied to the system. The components that produce emission are CHP, boiler and Grid electricity. The rate of emission production is mentioned in table.1. apart from these constraints, we want to establish an energy hub that is matched with climatic regulations like reaching net-zero energy production until 2050. As a result, we set a limitation on the emission the systems are allowed to produce. Based on that limit, the systems should reduce its emission by 50 percent (5 percent each year) until the last year of the simulation.

$$CO2_y \leq 0.95 * CO2_{y-1} \quad for\ all\ years \qquad (2\text{-}24)$$

The constraint (2-10) says that the emission of the year y should be 95 percent or less that that rate of the year y-1.

$$CO2_9 \leq 0.50 * CO2_1 \qquad (2\text{-}25)$$

The constraint (2-10) illustrates that the emission of the year 9 (the last year) should be equal or less that the first year of the modelling (year 0).

Results

In this study, the time slices are 96 as it was mentioned in table,1. This is because we have four seasons and each season does have 24 hours. The results are depicted based on these 96 hours.

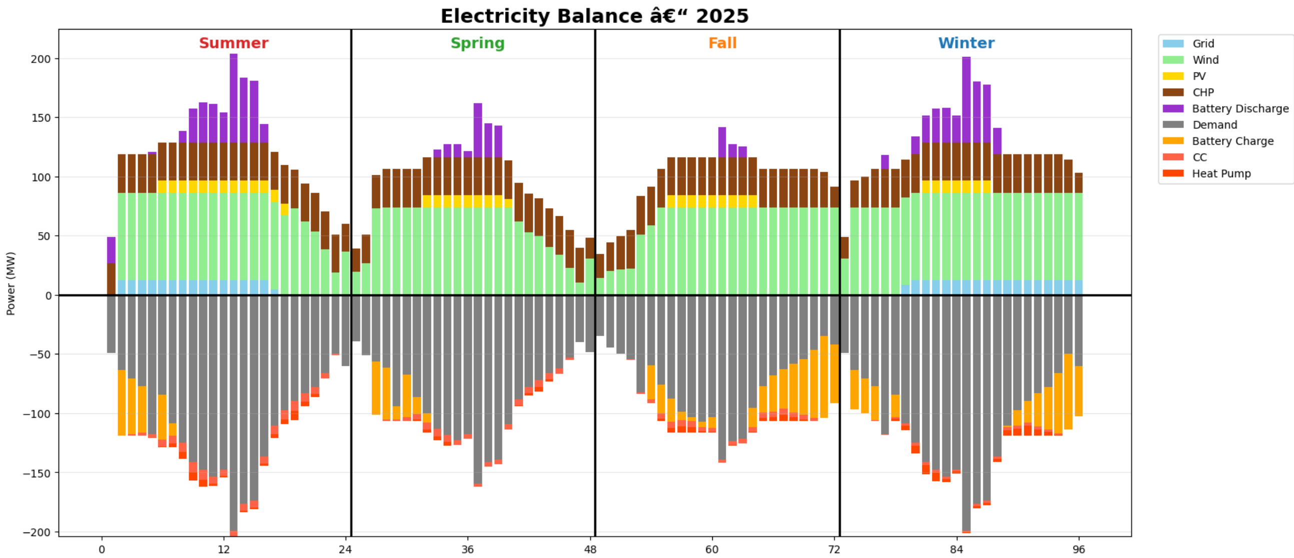

Fig. 3. Electricity balance in year 2025 (base year that is considered as 0 in modelling)

In year 2025, or the base year of the modelling, the distribution of energy production and consumption is shown in Fig. 3. As it is clear, the most electricity is produced by the wind. Then the CHP is the biggest producer of electricity. The reason why the solar PV energy production is very low is because of the lack of space in the ground of the industrial park. Its production is limited as we only have 15 hectares and this would

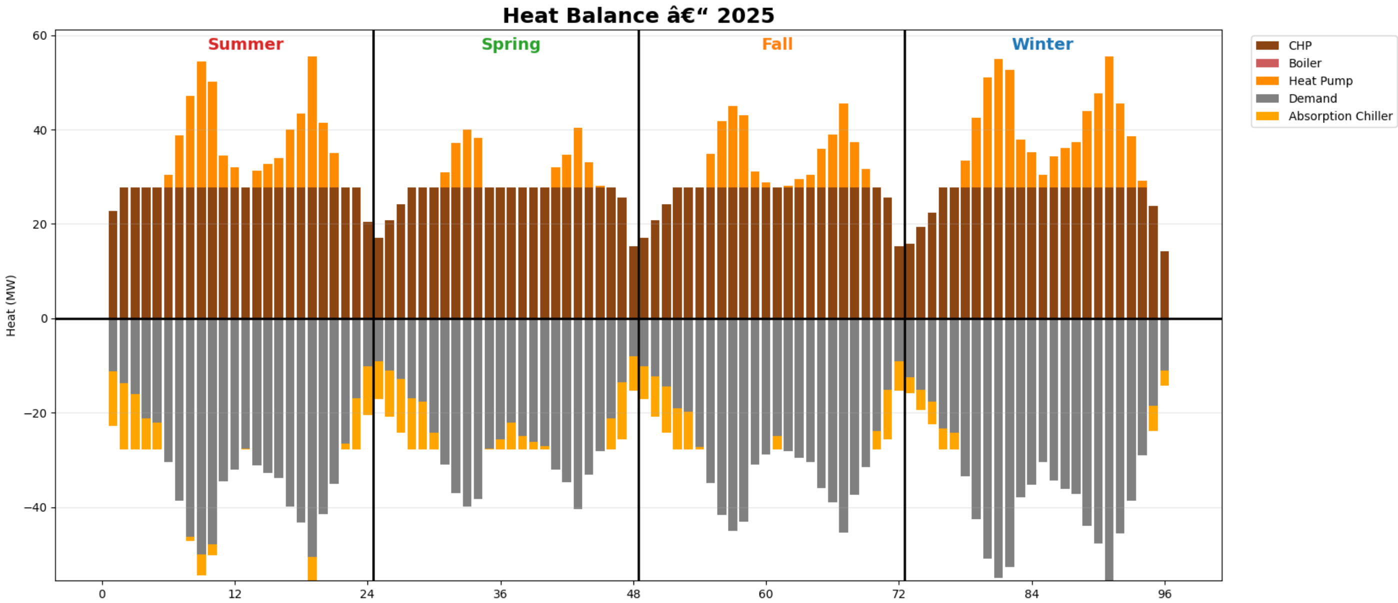

Fig. 4. Heating balance in year 2025 (base year that is considered as 0 in modelling)

approximately would produce 10 Mw of electricity in each hour by the PV. Also, it can be seen that the solar PV is used in different ours in each season. It is because of the accessibility to solar radiation during the day in each season. A very favourable result the usage of battery. First, the charge and discharge of the battery did not happen as we designed a constraint for that. Secondly, the battery saves the energy in not-peak hours and inject that to the industrial park in the peak ours. In this way, we can say that the battery has shaved the peak demand. Also, the model used grid electricity at some hours in summer and winter. In the negative side of the Fig. 1, the demand is shown as grey columns, the battery charge is orange, the HP electricity demand is red and the CC electricity need is pink. So, this diagram shows that the electricity balance is satisfied.

In Fig. 4, the heat balance is depicted. It is shown that the CHP produce a constant amount of heat in the energy hub. Then in the peak ours, the HP assisted CHP to satisfy the heating demand. Here, this question may be asked that "why the boiled is not used?" the main reason is the other two components. CHP is a component that is being used for electricity production in addition to heating production. Moreover, the HP has the COP of 3, which means it can produce 4 times heat as compared to its input electricity. Also, by applying the emission limitations, the model decided to consider HP and use CHP which can have efficiency of up to 80 per cent, which is 10 percent higher that the boiler. In the negative side, the heating demand is shown by grey columns and the heat needed by the AC is shown by orange columns.

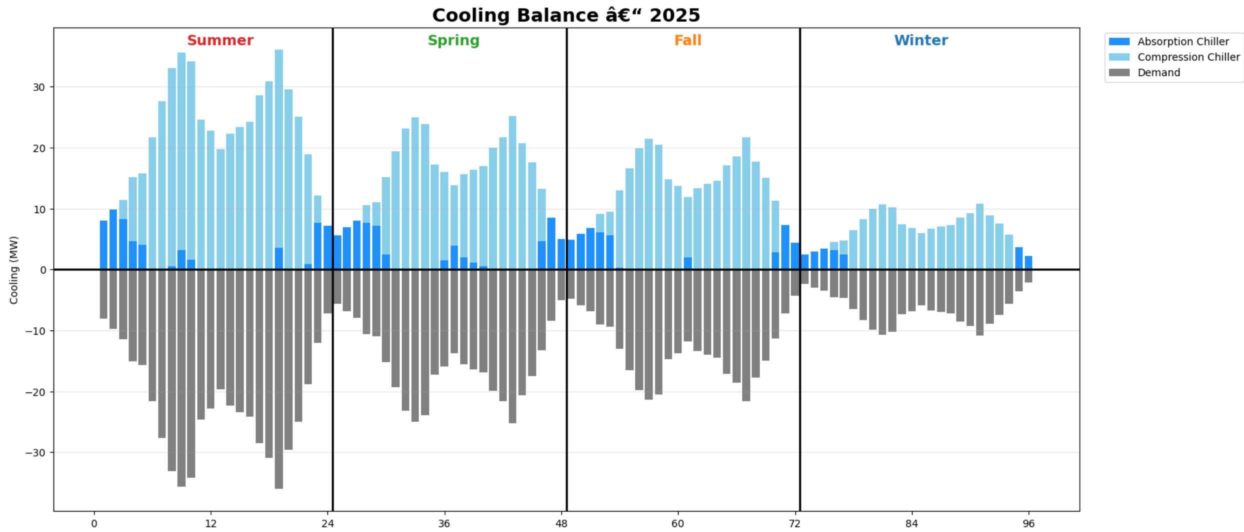

Fig. 5. Cooling balance in year 2025 (base year that is considered as 0 in modelling)

The cooling balance is illustrated is Fig. 5. The majority of cooling is supplied by CC, particularly in the not-peak hours. However, the AC is being used in the first and last hours of the day. This shows that the heating supply to the AC is happening at the 3 up to 4 hours of the day, in addition to 2 last hours and in the seasons that the cooling demand is higher, namely summer, in some hours mid-day. The cooling demand is shown as grey columns.

As it was mentioned before, the modelling considered 10 years. Consequently, we have to look at the percentages of each technology usage and their variation through 10 years. These results are depicted in Fig. 6, Fig. 7 and Fig. 8.

In Fig.6, as it was said before, the highest amount of electricity is produced by the wind. In the Fig. 6 the dark blue line shows the wind electricity yield over 10 years. At the bottom, the PV can be seen (orange line). The renewable energy sources (RESs) maintained their production as they don not emit any CO2. The same principle will be applied for Battery in terms of CO2 emission. However, the usage of the CHP decreases to almost 10 percent in the last year comparing to 30 per cent in 2025. In other words, climatic limitations have dropped the usage of CHP as it emits CO2. It has to be mentioned that the grid electricity usage firstly decreased to 3 percent and then went up to nearly 20 percent. The reason why this happened is because the systems decreased the amount of CO2 it is allowed to produce by declining the utilization of the CHP. In other words, decreasing the usage of CHP was enough to satisfy emission constraints. This let the model to use grid electricity as its cost is lower as compared to other sources. You may ask that the PV is cheaper than the grid, why the model did not utilized PV? The answer is owing to the max allowed solar electricity production, which is 10Mw.

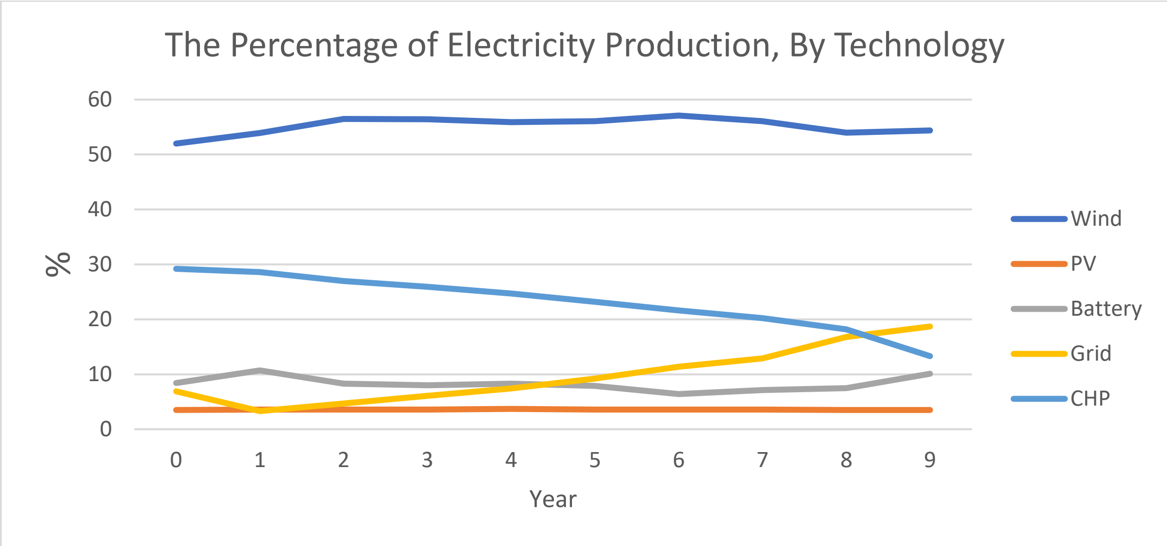

Fig. 6. The line diagram of electricity production variation of different technologies over 10 years

The changes in the heat production by each technology in heating section is depicted in Fig. 7. The boiler has not been used during the 10 years at all. As it was seen in Fig.1 the boiler was not utilized even in the first year that the constraint of the emission was not very hard. Consequently, boiler was not a favourable technology to use. In contrast, the CHP and the HP generated heat during all of the 10 years. However, the trends of them are completely against of each other. During the 10 years of modelling, because of the emission constraints, which gets harder as years pass, the CHP usage went down by more or less 45 per cent. Whereas the HP has to fulfil the absence of CHP and its production went up by 48 per cent. Also, this tells us that by applying emission constraints, the system naturally goes through electrification.
In Fig. 8, the changes in the percentages of cooling production by AC and CC is illustrated. As we approach the last year of the modelling, the amount of cooling yield by the AC dropped. This is because the COP of the CC is 4 and also uses electricity, not the heat. This is important as CHP is being used even in the last year of the modelling and using AC can increase the utilization of the CHP and thus, this would lead to more CO2 emission than allowed. So, the model decided to use CC more over the years and decline the usage rate of the AC.

By applying emission constraints, the amount of CO2 decreased to 8,708 kg from 17,415 kg, which shows exactly 50 per cent decline. The CO2 emission in each year is depicted in Fig. 9.

The most crucial result of this paper is that the dependency to electricity grid declined at least 80 per cent. This means the blackouts do not have the impacts they had before and thus, the production of the industrial park is not influenced as much as before and this will lead to more monetary benefits and less unit overhauls.

Reliability Analysis

If the industrial park wanted to supply its energy demands, some unintegrated energy production units, like diesels, had to be used. Also, all of the electricity demand used to be supplied by grid. However, in the proposed energy hub, there are 5 ways of electricity supply as shown in Fig, 11.

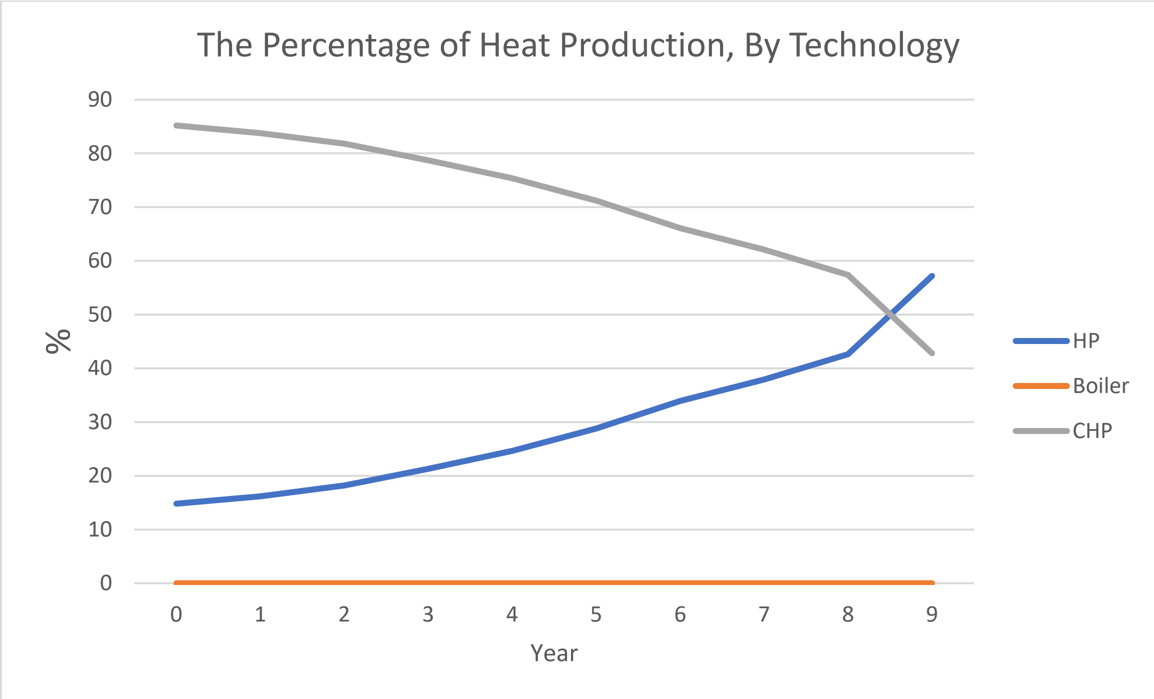

Fig. 7. The line diagram of heating production variation of different technologies over 10 years

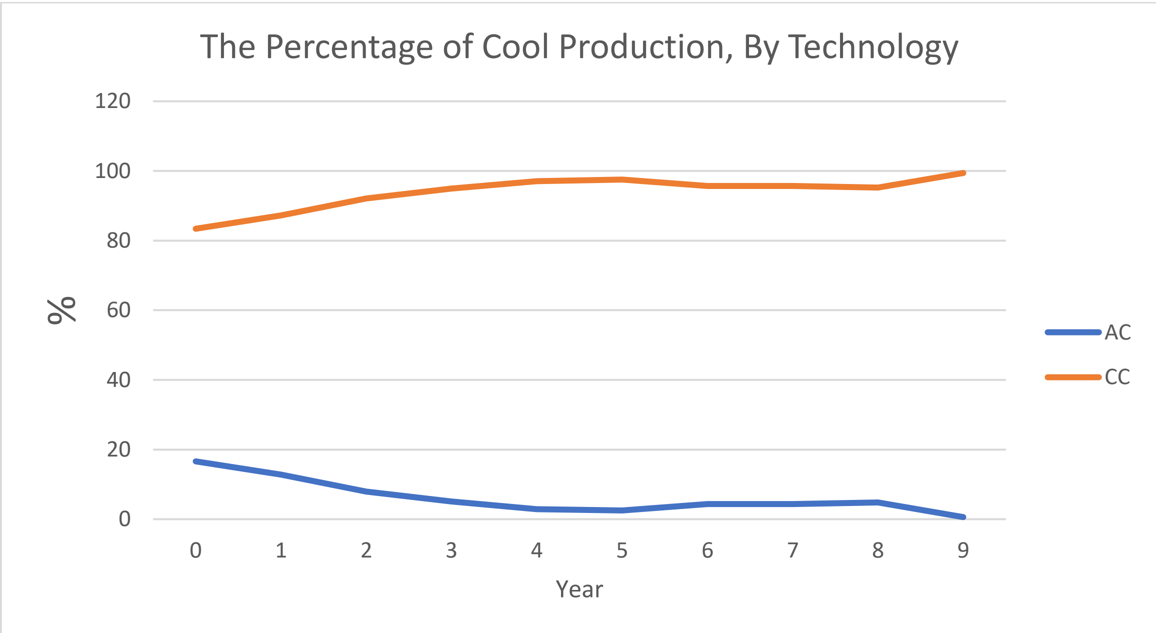

Fig. 8. The line diagram of cooling production variation of different technologies over 10 years

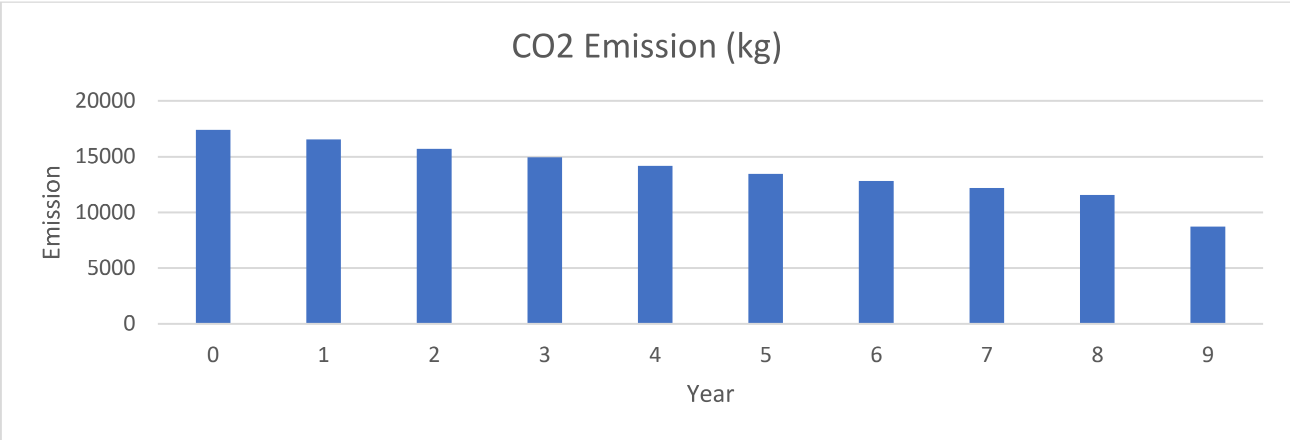

Fig. 9. The amount of annual CO2 emission

If we assume that each of the components have a reliability equal to 0.99, when all of the electricity is supplied by the grid, the reliability of the systems for electricity supply is 0.99. Nevertheless, when the energy hub concept is utilized, it means that the electricity can be produced using five sources which are in parallel form. For this system, the reliability is as below:

$$R_{system} = 1 - \left((1 - R_{CHP}) \times (1 - R_{wind}) \times (1 - R_{PV}) \times \left(1 - R_{grid}\right) \times \left(1 - R_{battery}\right)\right) = 1 - \left((0.01)(0.01)(0.01)(0.01)(0.01)\right) = 0.9999999999$$

If we compare the result with the previous form, which the reliability of electricity was 0.99, the total reliability of the electricity supply has been increased by 1.01 per cent.

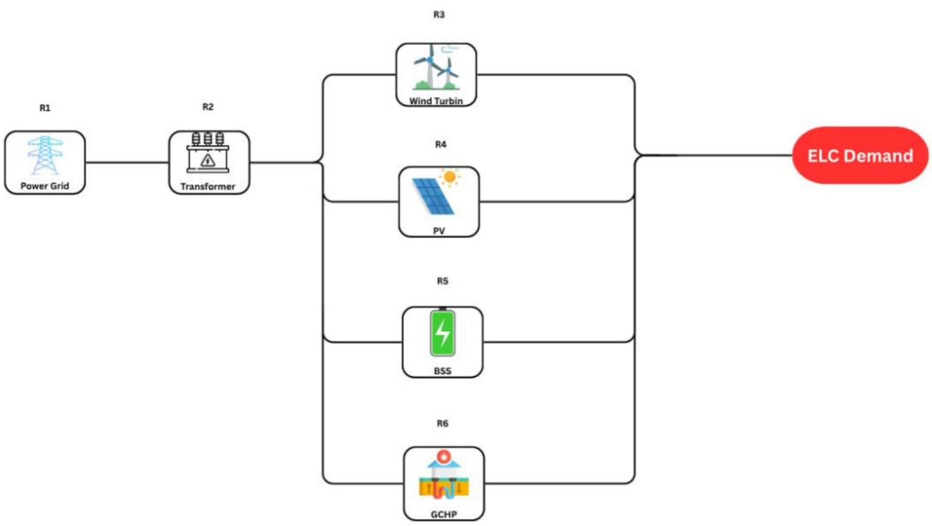

Fig. 10. The superstructure of electricity supply for reliability analysis

Sensitivity Analysis

It has been mentioned that the dependency of the industrial park would be declined to at least 20 percent by energy hub utilization. But a good question is "what can we do to use zero grid electricity?" by testing the model, it was realized that by increasing the amount electricity cost, the usage of the grid electricity would go down significantly. The operational cost of the grid electricity was considered to be 5 per cent of the its investment cost. However, by increasing this percentage to 15 per cent, the model no longer considered grid electricity owing to its high price. Fig. 11 shows the line diagram of the sensitivity analysis in the last year of the modelling.

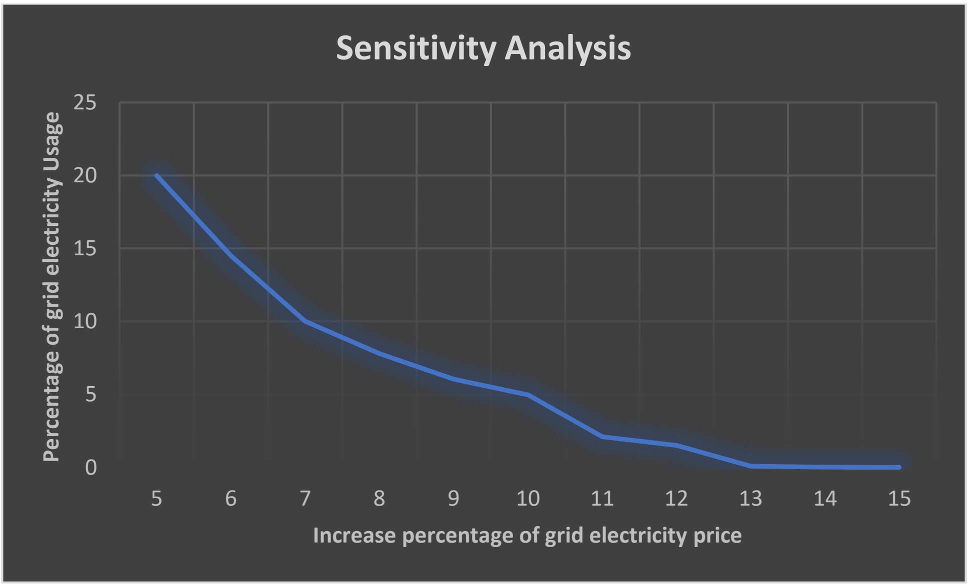

Fig. 11. Sensitivity Analysis of grid electricity price

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